International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 8, Issue 6, Dec 2018, 263-274

PREDICTION OF CUTTING FORCE IN TURNING OF Ti-6Al-4V UNDER MINIMUM QUANTITY LUBRICATION (MQL) USING RESPONSE SURFACE MODEL AND FUZZY LOGIC MODEL

RAVINDRA. R MALAGI[1], SANJEEVKUMAR. R CHOUGULA[2] & RAVIRA. J SHETTY[3]

[1]*Department of Product Design and Manufacturing, Visvesvaraya Technological University, Belagavi, India*

[2]*Research Scholar, Research Resource Centre, Visvesvaraya Technological University, Belagavi, India*

[3]*Department of Mechanical and Manufacturing, Manipal Institute of Technology, Manipal University, Manipal, India*

ABSTRACT

Titanium Alloy's (Ti-6Al-4V) are utilized in many manufacturing fields due to their exclusive properties. Machining of these materials has become a problem for metal cutting industries due to its chemical reaction on tool material. Thus metal cutting industries are looking forward for identifying the optimum cutting parameters during turning of Ti-6Al-4V. Hence in this paper, Response Surface Model and Fuzzy Logic model has been used to estimate and optimize cutting conditions for cutting force during turning ofTi-6Al-4Vunder Minimum Quantity Lubricant condition. From the observations of these two approaches we can conclude that Response Surface Model and Fuzzy Logic model can be effectively used for identifying the optimum cutting parameters and preventing time consuming experiments.

KEYWORDS: Ti-6Al-4V, Minimum Quantity Lubricant, Cutting Force, Response Surface Model & Fuzzy Logic

Original Article

Received: Aug 17, 2018; **Accepted:** Sep 17, 2018; **Published:** Nov, 01, 2018; **Paper Id.:** IJMPERDDEC201831

INTRODUCTION

Ti-6Al-4V is the most popular and are widely used in aviation, aerospace, ship building, and biomedical, chemical and other industrial departments due to its excellent properties [1]. Minimum quantity lubrication (MQL) also recognized as near dry machining and has been widely studied by many researches [2-8].

The experimental research by [6-7] indicated that the MQL helps in reducing process output parameters such as cutting force and better surface roughness based upon cutting speed, feed rate and depth of cut. [8] carried out research on minimum quantity lubrication on surface irregularity during dry flooded machining. [9] in their investigation it was found that minimum quantity lubrication gave better performance compared to dry and wet machining.[10]performed machining ofTi-6Al-4V alloy using different tools and cooling conditions.[11-12] optimized the cutting condition on turning of Ti-6Al-4V. [13] Carried out research on turning of Ti-6Al-4V alloy and generated second-order response surface model. [14] From their literature it was observed that fuzzy logic and response surface methodology can be applied successfully to predict process output variables. [15] Has combined the grey, fuzzy and Taguchi approaches. [16] Used fuzzy rule based model for prediction of process output parameters in turning of titanium alloy. From the available literature there has been limited studies regarding cutting force prediction and correlation between Response surface model and Fuzzy logic model. Hence, an attempt has been made in this paper to study the effect of cutting force during turning of Ti-6Al-4V

under minimum quantity lubrication condition using Response surface model and Fuzzy logic model.

EXPERIMENTAL

The experiments were carried out in PSG A141 lathe (2.2 KW). The machining experiments were carried out using Cubic Boron Nitride inserts KB-90 (ISO code) under Minimum Quantity Lubrication (MQL) condition (Figure 1). In MQL application, the coconut oil as lubricant is supplied to the cutting zone by a specially developed test rig. Details of cutting tool and tooling system used for experimentation are shown in Table I.

Figure 1: Experimental Set Up

Table I: Details of Cutting Tool and Tooling System

Tool Holder	CTGPR 1212 F 11
Tool Geometry	Approach angle:91^0 Tool nose radius:0.4 mm Rake angle: 0^0 Clearance angle: 7^0
Tool Insert CBN(KB-90)	TPGN 110304-LS

MATERIAL

The Ti-6Al-4V in a form of round bars were supplied by Baoji Yongshegtai Titanium Industry Co., Ltd China and procured through HAL, Bangalore. Ti-6Al-4V is an (α+β) alloy of aerospace Grade 5. Figure 2 shows the microstructure of Ti-6Al-4V specimen. The mechanical properties of Ti-6Al-4V specimen at room temperature are shown in Table II. Chemical compositions of Ti-6Al-4V are given in Table III. Table IVshows the cutting parameters selected for experimentation.

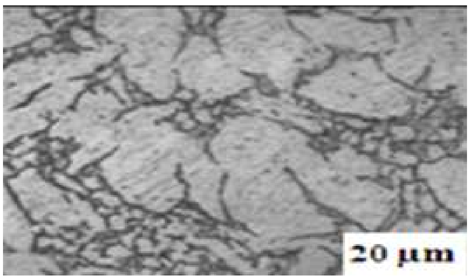

Figure 2: Microstructure of Ti-6Al-4V Specimen

Table II: Mechanical Properties of Ti-6Al-4V

Property	Typical Value
Hardness, Rockwell	30
Ultimate Tensile Strength (MPa)	955
Yield Tensile Strength(MPa)	900
Modulus of Elasticity (GPa)	113.8
Poisson's ratio	0.342
Density(g/cm^3)	4.51
Elongation in 4D (%)	18
Reduction of area (%)	42
Fatigue Strength (MPa) (at 1E+7 cycles. K_t stress concentration factor-3.3)	240

Table III: Chemical Composition (Wt %) of Ti-6Al-4V

Element	Al	V	Fe	O	C	N	Y	H	Ti
Wt (%)	6.1	4	0.16	0.11	0.02	0.01	0.001	0.001	Bal

Table IV: Cutting Parameters for Experimentation

Lubrication Conditions	Cutting Speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Rake angle (deg)	MQL Pressure (bar)	Nozzle Diameter (mm)	Nozzle Distance (mm)	MQL Temperature (deg)
MQL	45 73 101	0.11 0.18 0.25	0.25 0.50 0.75	0	5	5	20	35

MINIMUM QUANTITY LUBRICATION

In MQL type application, the experiments were conducted using coconut oil as lubricant which is made to flow along with high pressure compressed air through a thin-pulsed jet nozzle. The schematic diagram of MQL Set up employed in the current investigation is shown in Figure 3.

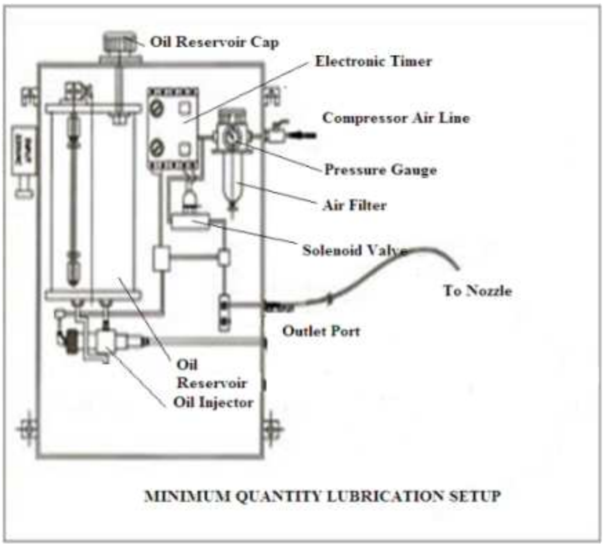

Figure 3: Schematic Diagram of MQL Set up

CUTTING FORCE MEASUREMENT

The cutting force generated during turning of Ti-6Al-4Vtitanium alloy under minimum quantity lubrication condition is measured by 9257BA KISTLER Dynamometer. The signals of cutting force are transmitted to KISTLER 5070 charge amplifier and recorded on a personal computer subsequently. Figure 4 shows the cutting force measurement layout.

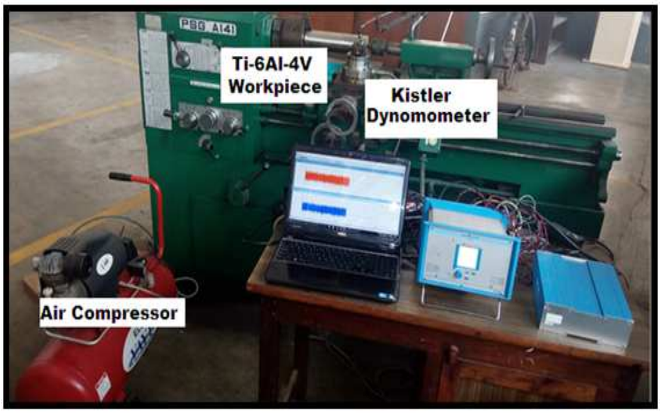

Figure 4: Force Measurement Layout

RESPONSE SURFACE MODEL

Response surface methodology (RSM) has been used by many researchers to analyse the relationship of process input parameters with process output parameters [17-21].

In this paper, 20 sets of experiments are carried out for experimentation. The relationship between the output variable '*y*' and the turning parameters (*A, B and C*) is expressed in the form of a second degree linear polynomial regression equation [22].

$$y = \beta_o + \beta_1 A + \beta_2 B + \beta_3 C + \beta_4 A^2 + \beta_5 B^2 + \beta_6 C^2 + \beta_7 AB + \beta_8 AC + \beta_9 BC + \varepsilon$$

where, β_0, β_1, β_2, ….β_9 are the regression coefficients and ε is the random error.

FUZZY LOGIC BASED MODEL

Fuzzy Logic Based Model helps in predicting the cutting parameter the cutting parameters that effect cutting force [23] obtained by response surface model during machining of Ti-6Al-4V. In the developed fuzzy model three input parameters Cutting speed, feed and depth of cut are considered. The fuzzy logic aims at the systematically generating fuzzy rules from given input/output data (Figure 5).

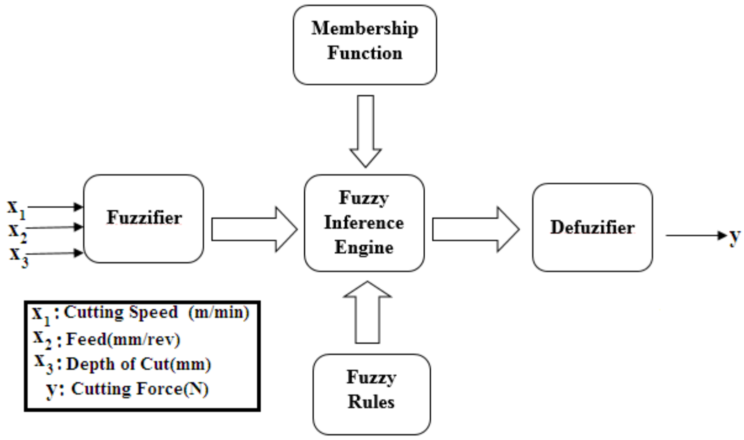

Figure 5: Structure of Fuzzy Logic System with Three Type's Inputs and Output

RESULTS AND DISCUSSIONS

Concept of metal machining can be effectively understood by predicting the cutting force. From the available literature on machining of Ti-6Al-4V reveals that these aspects have been given more attention still due to the complex deformation between tool and work it is often necessary to explore the behavior of Ti-6Al-4V during machining.

CUTTING FORCE (RESPONSE SURFACE MODEL)

In response surface model a second-order model is generated for cutting force for selected levels and factors in machining of Ti-6Al-4V is shown in Table V.

Table V: Levels and Factors (Response Surface Methodology)

Levels	(A) Cutting speed (m/min)	(B) Feed (mm/rev)	(C) Depth of Cut (mm)
1	45	0.11	0.25
2	101	0.25	0.75

Table VI: Analysis of Variance for Cutting Force (N)

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P	P%
Cutting Speed (m/min)	2	5.39497	5.39497	2.697748	521.04	0.000	82.57
Feed(mm/rev)	2	0.25052	0.25052	0.12526	24.20	0.000	3.83
Depth of cut(mm)	2	0.66850	0.66850	0.33425	64.56	0.000	10.23
Cutting speed(m/min)*Feed(mm/rev)	4	0.42567	0.42567	0.10642	20.56	0.000	3.26
Cutting speed(m/min)*Depth of Cut(mm)	4	0.001125	0.001125	0.00079	0.15	0.956	0.024
Feed(mm/rev)*Depth of Cut(mm)	4	0.041125	0.041125	0.00281	0.54	0.709	0.086
Residual Error	8	0.04142	0.04142	0.00518			
Total	**26**	**6.79548**			**631.05**		

From the observed data for cutting force, the response function has been determined in uncoded units as:

$$\text{Cutting force (N)} = 194.63 - 1.258A + 0.958B + 25.26C + 0.0062A^2 + 172.45B^2 - 2.98C^2 - 0.181AB - 0.043AC - 53.72BC \quad (1)$$

Result of ANOVA for cutting force is presented in Table VI. From the analysis it was observed that F calculated

value was more than F-table value hence the second order mathematical model generated can be used in turning of Ti-6Al-4V.

From equation (1) contour and surface plot for each of the response surfaces at different cutting speed-feed planes at different depth of cut is plotted Figure 6.

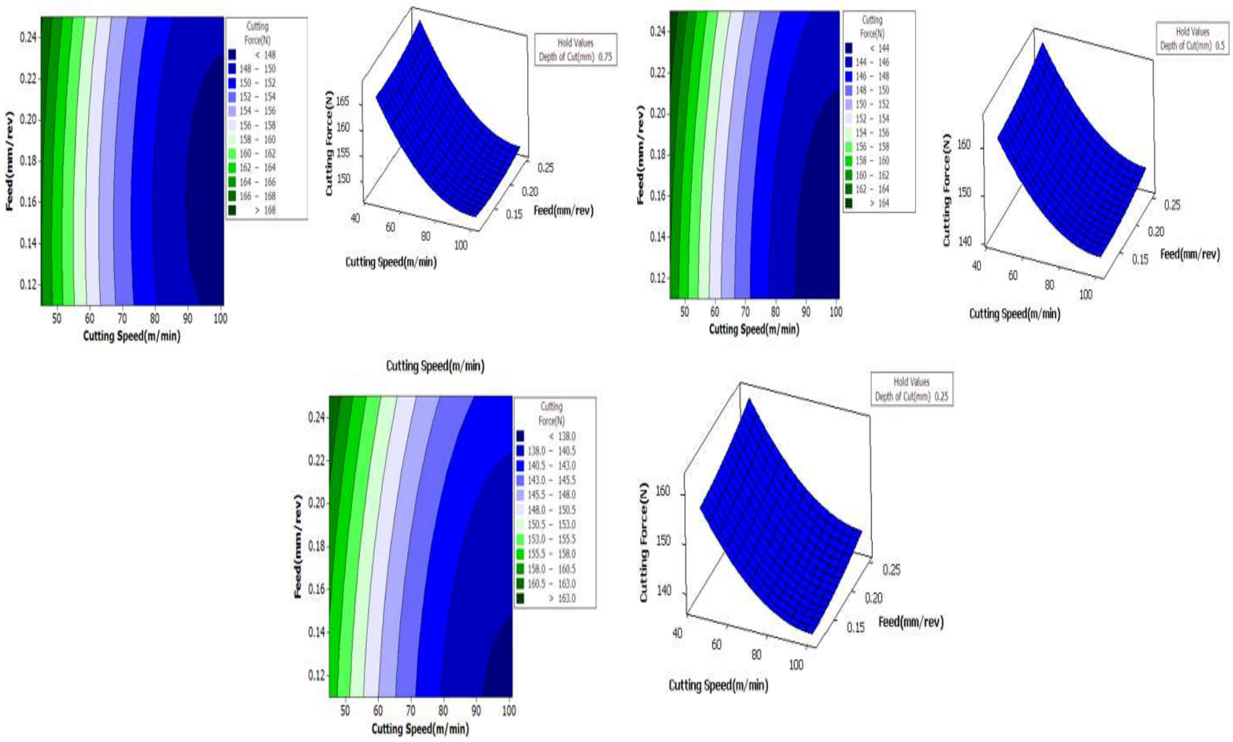

Figure 6: Cutting Force Contour Plot and Surface Plot in Cutting Speed- Feed Planes at different Depth of Cut

CUTTING FORCE (FUZZY RULE BASED MODEL)

Fuzzy logic has been effectively used for inexact reasoning generated by mathematical theory. From the analysis cutting force generated for Minimum and Maximum values of input/output parameters for different cutting parameters based on Fuzzy Rule Based Model are shown in Table VII which clearly indicates that at minimum cutting sped, feed and depth of cut gave lower cutting force values than that of maximum cutting speed, feed and depth of cut. Further it was observed that lowest cutting force (143.93N) were obtained at cutting speed of 45m/min, feed rate of 0.11mm/rev and depth of cut of 0.25mm and at cutting speed of 101m/min, feed rate of 0.25mm/rev and depth of cut of 0.75mm cutting force (164.99N). From the results, we can conclude that selection of 45m/min, feed rate of 0.11mm/rev and depth of cut of 0.25mm is the optimum condition for achieving lower cutting force value obtained from Fuzzy rule editor which can be seen in Figure 7. Membership function plot for Cutting Force for different cutting parametersis shown in Figure 8.

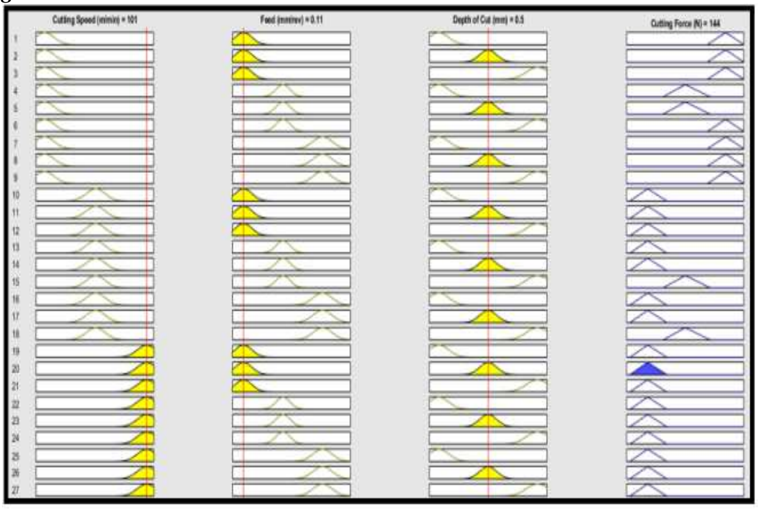

Figure 7: Fuzzy Rule Editor

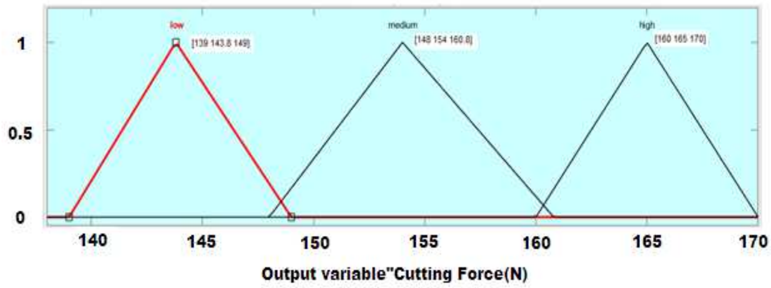

Figure 8: Membership Function Plot for Cutting Force

Table VII: Minimum and Maximum Values of Input / Output Parameters

Parameters	Input/output	Minimum value	Maximum value
Cutting Speed (m/min)	Input	45	101
Feed (mm/rev)	Input	0.11	0.25
Depth of cut (mm)	Input	0.25	0.75
Cutting force (N)	Output	143.93461	164.9980

FUZZY INFERENCE SYSTEM

Fuzzy logic toolbox of MATLAB version R2007b mamdani fuzzy expert system [23] generally used algorithm has been used as Fuzzy inference system. The input/output linguistics variables of the present study are set fuzzy intervals. The fuzzy membership function values are between 0 and 1.

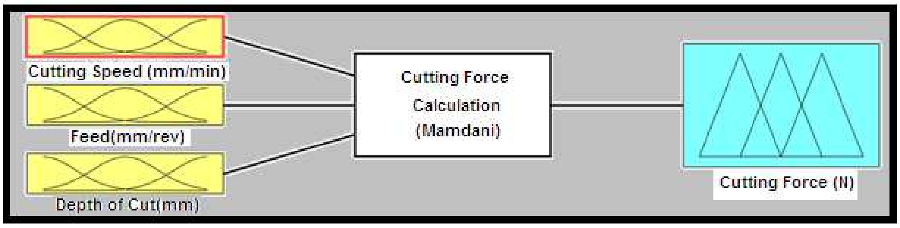

Figure 9: Fuzzy Inference System

The Figure 10, represents the effect of cutting speed and feed on Ti-6Al-4V work piece material. Initially the cutting force was very high which was ranging from 164Nand as the cutting speed increased from 45m/min to 101mincutting force decreased to 143.9N. This may be due to a higher cutting speed there is less contact between tool tip and the work piece which certainly reduces the frictional force exerted between chip tool interfaces which results in lower cutting force values.

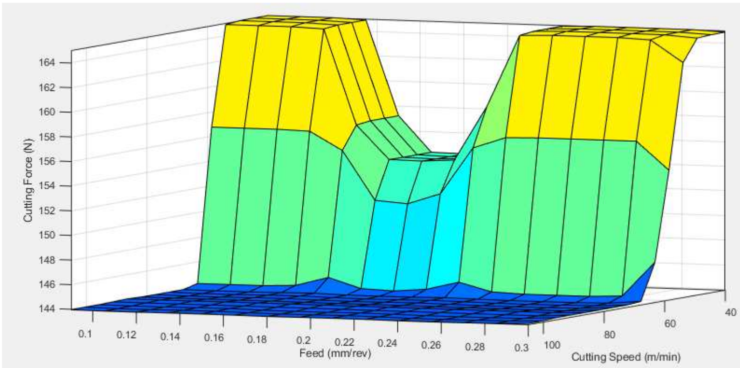

Figure 10: Effect of Cutting Speed and Feed on Cutting Force (N)

From Figure 11, low feed ranging from 0.11mm/rev to 0.16mm/rev, cutting force was uniform and as the depth of cut increased from 0.4mm to 0.75mm the cutting force was maximum. This may be due to more ploughing of the work material resulting in more frictional force.

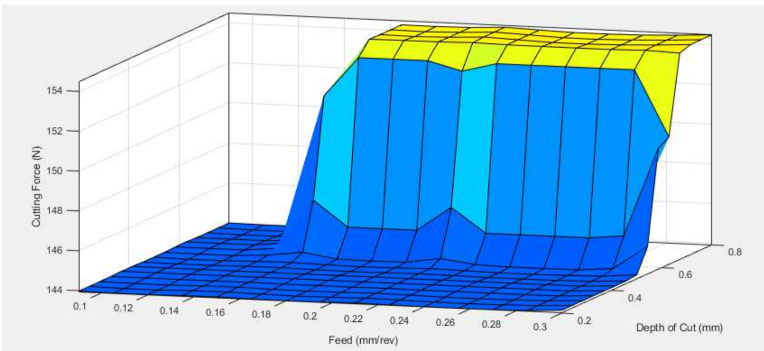

Figure 11: Effect of Depth of Cut and Feed on Cutting Force

The Figure 12 shows, that there was an increase in cutting force lower Cutting speed and higher Depth of cut and as the Cutting speed increased and depth of cut reduced the cutting force value reduced drastically. This may be due to less frictional force and less ploughing of the material.

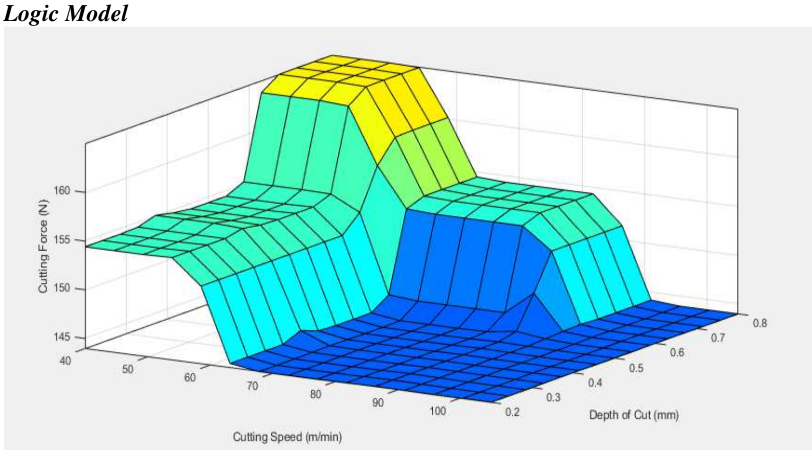

Figure 12: Effect of Depth of Cut and Cutting Speed on Cutting Force

From the comparison plots for Response Surface Model and Fuzzy Logic Model for cutting force(N) (Figure 13) validated with 10 data sets of fuzzy rules based Response surface model data collection it was observed that Response surface model value were almost nearer to the Fuzzy Logic Model.

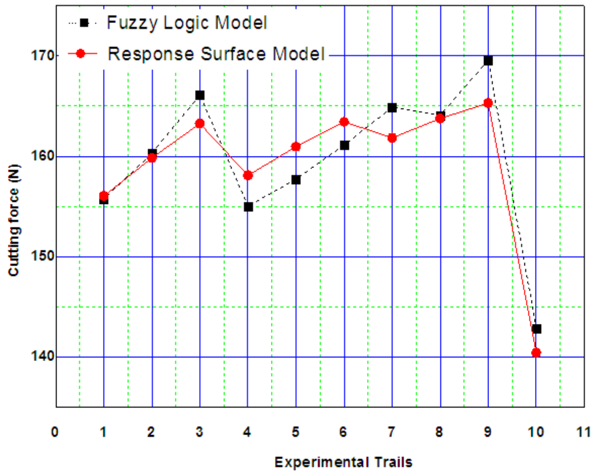

Figure 13: Comparison Plots for Response Surface Model and Fuzzy Logic Model for cutting force (N)

CONCLUSIONS

In this paper the Response surface model and Mamdani-type fuzzy logic model has been used to estimate cutting force during turning of Ti-6Al-4V. From the analysis of the development and application of the Response surface model and fuzzy logic model following conclusion can be drawn:

- The Response surface model generated helps in predicting cutting force at any region.
- Analysis of Variance for the cutting force was calculated to check for adequacy. From second order response function it was proved that developed model showed good results.
- From the results from Fuzzy rule based modelling we can conclude that selection of 45m/min, feed rate of 0.11mm/rev and depth of cut of 0.25mm is the optimum condition for achieving lower cutting force value.

- From the comparison plots for Response Surface Model and Fuzzy Logic Model for cutting force (N) validated with 10 data sets of fuzzy rules based Response surface model it was observed that Response surface model value were almost nearer to the Fuzzy Logic Model.
- The proposed Fuzzy logic model can be used for prediction of cutting force during turning of Ti-6Al-4V under Minimum Quantity Lubrication.

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